Study of Laser Distance Measurement Techniques

by

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INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

JULY, 1998

Study of Laser Distance Measurement Techniques

A thesis submitted

in partial fulfillment of the requirements

for the degree of

DIIT

by

K.S.V.PRASAD

to the

DEPARTMENT OF ELECTRICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY

KANPUR

July, 1998

EE-1998-M-PRA-STU

CERTIFICATE

This is to certify that the work, "Study of Laser Distance Measurement Techniques", has been carried out by K.S.V. PRASAD(Roll No.9712402) under my supervision, and it has not been submitted elsewhere for a degree.

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Dedicated

To

My Beloved Son

Sai Kiran

Acknowledgments

I would take this opportunity to express my sincere thanks to *Dr. Joseph John*, my thesis supervisor for his guidance given to me throughout my thesis. I am grateful to sir for his suggestions and advises. He has always been very patient during the thesis work.

I am thankful to all of my friends for their help and kind suggestions. I acknowledge the cheerful and warm company of all my classmates for the moments that we shared together and made my stay memorable.

Last, but not least, I take this opportunity to convey my heart felt gratitude to my parents, wife Parvathi and my son Sai Kiran for their moral support and inspiration.

Abstract

An effort has been made in this thesis to study different laser based distance measurement techniques.

As a part of the review, Laser radar principle, system requirements and performance are described. Three, phase difference based distance measurement methods are also discussed. Implementation of a range finder using a frequency modulated laser diode is discussed in detail. Design of subsystems, such as, laser driver circuit and photodiode amplifier circuit are covered.

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Chapter 1

Introduction

Optical distance measurements can be classified into two broad areas, viz.,

i) Long distance measurement(Ranging)

ii) Small distance measurement(Metrology)

The applications of ranging are mostly of military interest. The applications of metrology include robotics, control systems, manufacturing, surveying etc.

1.1 Lasers in Distance Measurement

With the invention of lasers, major improvements were possible in the area of optical distance measurement.

The two major principles used in distance measurement using lasers are

i) Time-interval measurement

ii) Phase change measurement

In time-interval measurements, the light emitted from the laser is allowed to hit the target whose distance is to be measured. A part of the light will be reflected back to the laser by the target. The round trip travel time of the light is measured and the distance is calculated from this.

In phase change measurements, the phase of the returning beam is compared to the transmitted one and the round trip time is calculated from the phase difference, from which the distance is computed.

The major laser distance measurement principles and applications can be tabulated as follows.

Principle	Applications	Advantages and Disadvantages
a)Time-interval Measurement	.Docking of Satellites in space .LRF's for tanks, aircrafts, observation posts .Depth of immersed objects under water .Cloud height, structure	.Quick measurement .Fairly accurate(1 in 10^3) 1-10m in km .Cooperation of target not required
b)Phase change measurement	.High accuracy measurements of distance for ground survey .Measurement of small movements(monitoring of dams.etc) .Interferometry	.Accuracy 1 in 10^6 .Takes time for measurement .Relatively costly .Cooperation of target required(use of corner cube reflectors)

Table 1. Laser Distance Measurement Principles and Applications

1.2 Laser Distance Measurement Methods[3]

Accurate measurements using laser beams can be performed by three different methods, which almost have complementary ranges as follows.

1. Interferometric techniques(up to $\approx$ 50m in free air)

2. Telemetry with modulated beams(from $\approx$ 100m to $\approx$ 50km)

3. Optical Radars(larger than 10km)

The interferometric distance measurements usually rely on the use of Michelson interferometer. Here the laser beam is divided by a beam splitter into measurement and reference beams. The reference beam is reflected by a fixed mirror, while the measurement beam is reflected by a mirror fixed to the object, the distance of which is being measured. For measuring distance the phases of the two beams are compared. Here frequency stabilized He-Ne lasers are generally used as light sources, as interference effects cannot be obtained with an optical path difference appreciably larger than the coherence length. Frequency stabilized lasers have a coherence length typically in the range of a thousand kilometers.

In modulated beam telemetry techniques, the phase of the transmitted beam is compared to the phase of the returning beam, and time taken by the beam to make the round trip(t_r) is calculated from the phase difference(ϕ) and the frequency of the modulating signal(f), using the relation

$$t_r = \frac{\phi}{2\pi f} \tag{1.1}$$

From the above time the absolute distance is calculated. Here He-Ne or GaAs lasers are used as light sources. Laser sources due to their higher brilliance contributed to an increase in measurement range and accuracy in these techniques.

In optical radar techniques, the distance is determined from the time of

flight of a short laser pulse(10 to 50ns) emitted by a Q-switched ruby or Nd:YAG laser or by CO_2 lasers.

1.3 Organization of the Thesis

Rest of the thesis is organized as follows. Chapter 2 gives a review of laser distance measurement methods. Different time interval as well as phase difference measurement techniques are discussed. In Chapter 3 the design and implementation of a range finder using frequency modulated laser diode is described. Chapter 4 is devoted to conclusions. A list of references is given at the end of the thesis.

Chapter 2

Review of Laser Distance Measurement Methods

In this chapter different distance measurement methods, using laser as the optical source, are reviewed and their performances compared.

2.1 Time Interval Measurement Methods (Laser Radar)

Time interval measurement methods incorporate laser radar principles. Several implementations of this technique are reported in the literature. Here the principle and performance of the laser radar are discussed followed by the system requirements of a coherent pulse-doppler radar. An implementation of laser radar technique using GaAs laser diode is also given.

2.1.1 Laser radar principle, and performance[1]

Principle

The same principle used in microwave radar measurements of distance can be used for laser radar distance measurements. Laser is aimed at a target and a short pulse is fired from the laser. The time taken by the light to hit the target and then return to the receiver at the laser end is measured. The measured time (t) is used to calculate the distance(D) from the equation,

$$D = \frac{ct}{2} \tag{2.1}$$

Where "c" is the speed of light.

The laser pulse width should be small if the distance is to be measured accurately. The uncertainty in distance measurements is given by the equation,

$$DU = \frac{cL}{2} \tag{2.2}$$

Where "L" is the pulse width and "DU" is the uncertainty in distance

For example, if the pulse width is $1\mu s$ the distance uncertainty is 150m whereas, for a pulse width of 10ns the distance uncertainty is 1.5 meters. In practice the distance uncertainty is also strongly affected by the accuracy of pulse timing and measurement electronics.

Performance

Laser radars have performances similar to microwave radars. The higher optical frequency has the beneficial effect of smaller components and remarkable angular resolution. The atmospheric attenuation losses, however, are considerable at these high frequencies.

Laser systems built to operate on the ground are usually of limited range (about 10km), primarily because of atmospheric attenuation effects. Space-borne laser systems, however, can be built with ranges in thousands of kilometers in the absence of atmospheric attenuation.

Laser radars, primarily because of atmospheric windows, and the availability of detectors, are constructed at 1.06 and 10.6μm wavelengths. The 1.06μm laser radar systems are referred to as Nd:YAG crystal laser systems whereas 10.6μm laser systems are called CO_2 gas laser systems. The solid state laser systems at 1.06μm are not as efficient (1% efficiency) as the CO_2 laser systems at 10.6μm (10% efficiency)

2.1.2 System Requirements of a Coherent Laser Pulse-Doppler Radar[6]

In a conventional optical receiver the received optical signal is fed alone into the detector. In a coherent optical receiver, the received optical signal is summed with a coherent optical reference (called the local-oscillator reference) and the summed optical signal is fed to the photo-detector. The squaring process of the detector effectively multiplies the received signal and the local-oscillator reference together, and the bandwidth narrowing of the subsequent amplifier effectively integrates the resultant product. This combination of multiplication and integration in a coherent detection performs a cross-correlation, which allows the receiver to achieve considerably greater sensitivity than one employing non coherent detection. Fig 2.1 gives the block diagram of a coherent laser radar.

A CW[1] laser oscillator, generates a signal at optical frequency F_o. This is fed to a pulse modulated laser amplifier, which generates a pulsed optical signal of carrier frequency F_o. The target echo frequency is shifted from the transmitted frequency F_o by the doppler shift F_d and so has a carrier frequency of F_o+F_d. An

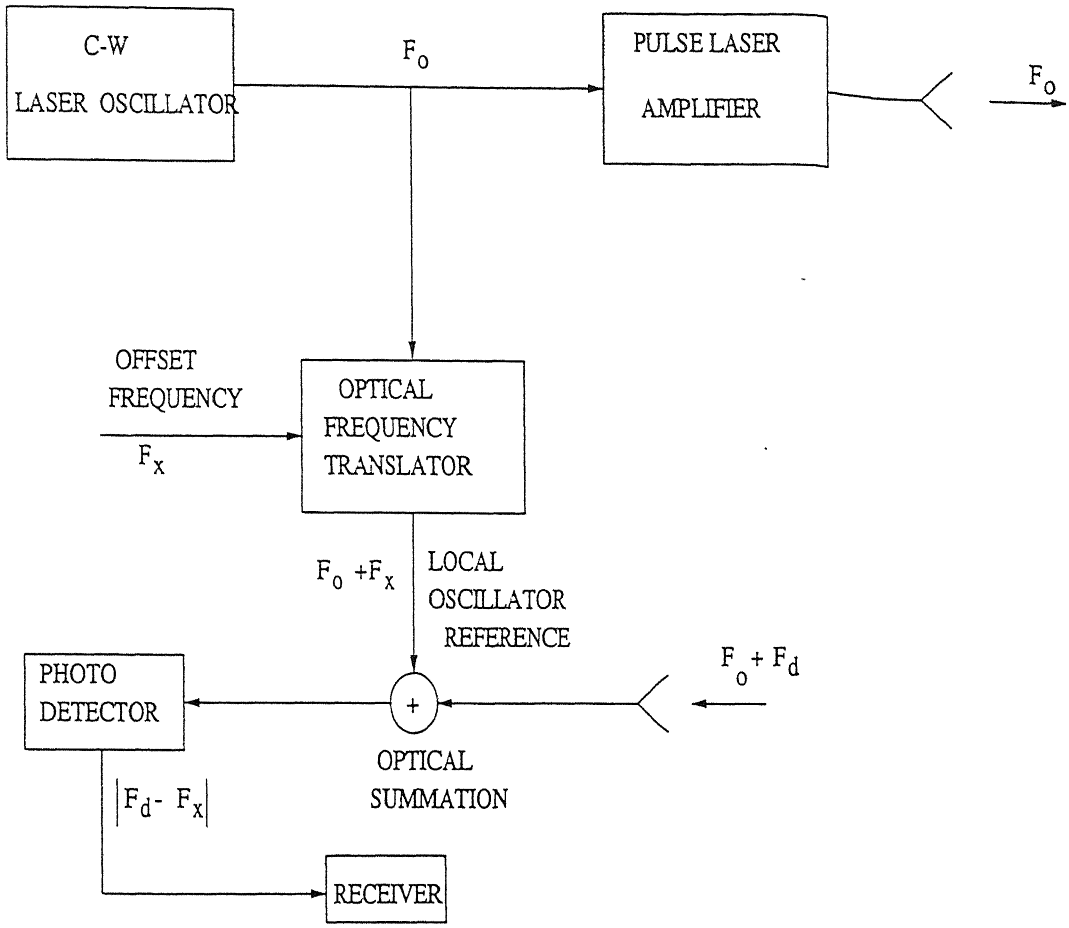

Figure 2.1: Block Diagram of a Coherent Optical Radar

optical frequency translator is often needed to shift the local oscillator frequency from the frequency F_o of the CW laser oscillator by an offset frequency F_x. Thus the local oscillator signal has a frequency of F_o+F_x. The local oscillator signal and target echo signal are summed together optically and fed to the photo-detector. The photo-detector gives as an output a signal at the difference between the target echo frequency F_o+F_d and the local oscillator frequency $F_o + F_x$ which is thus at the frequency $F_d - F_x$. This signal is fed to the receiver.

The target doppler frequency shift F_d is given by the following expression.

$$F_d = \frac{2V}{\lambda} \tag{2.3}$$

Where V is the relative closing velocity and λ is the wavelength of the optical signal.

Laser radar systems are quite useful in space vehicle applications. Relative velocities for such applications may be as high as 10 miles per second, which represents the relative speed between two low altitude satellites traveling in opposite directions. The doppler shift at the ruby laser wavelength for this extreme condition is 50GHz.

If a frequency translator were not used, the photo-detector would have to pass the doppler frequency which could be as high as 50GHz for a space vehicle application. By using a frequency translator, the photo-detector need merely pass the difference between the doppler frequency F_d and the offset frequency F_x which can be relatively small.

Although the frequency translator allow the detector to operate with a bandwidth much less than the doppler shift, it is usually desirable that the detector have the widest possible bandwidth in order that it can simultaneously examine the largest possible region of doppler frequencies during search.

To achieve optimum detection, the pulse width should be equal to $1/\Delta$f, where Δf is the receiver bandwidth. For a Δf of 10MHz pulse width must be 0.1μs. Such a laser radar system would achieve a speed resolution of $\approx$3m/sec and a range resolution of $\approx$15m. It also would have very high angular resolution. Thus a laser radar is capable of achieving very high resolution in speed range and angle. In contrast a microwave radar has relatively poor angular resolution.

The laser radar has much greater resolution capability than a microwave radar but is far inferior in search. The poor search capability is due to

1. Its high noise figure.
2. The generally smaller capture area of its receive aperture.
3. The low efficiency of lasers.

For this reason laser radars will usually be operated in conjunction with

microwave radar, which will perform the coarse search function. The laser radar will generally search over only a relatively small region of range, speed and angle.

2.1.3 GaAs Injection Laser Radar[7]

Gallium Arsenide(GaAs) Injection lasers, radiating in the wavelength region of 840-900nm, have several characteristics which make them attractive in specialized radar applications for such functions as ranging, altimetry etc. The attractive features of GaAs lasers are

1. The lasers are diodes of small size and weight.
2. Direct current is converted directly to infrared radiation with high internal efficiencies.
3. Efficient room temperature operation.
4. The lasers can be directly modulated with short pulses or high frequency waveforms.

In comparison to ruby lasers, however, injection lasers are relatively low power devices. Typical output peak power from a single laser may be on the order of 10-100 watts. Also, the radiation wavelength of GaAs is temperature dependent (It shifts about 0.25nm/^{o}K at room tempatature) so that depending on the application, some temperature stabilization may have to be provided.

The range capability of GaAs radar depends on system parameters and the operational environment. On earth, the atmosphere presents well-known hazards to optical and infrared operation. But even in space environment the ability to detect target echoes depends on the ever present background radiation. At night the effect of background radiation is usually negligible. In daytime, however, background radiation may be the predominating source of noise and may severely limit the radar performance. To minimize the background radiation noise, a narrow band optical

filter and a narrow field of view consistent with the spectral width of the signal radiation and the transmitted beam-width need to be incorporated into the radar. Fig 2.2 shows the block-diagram of a GaAs laser radar.

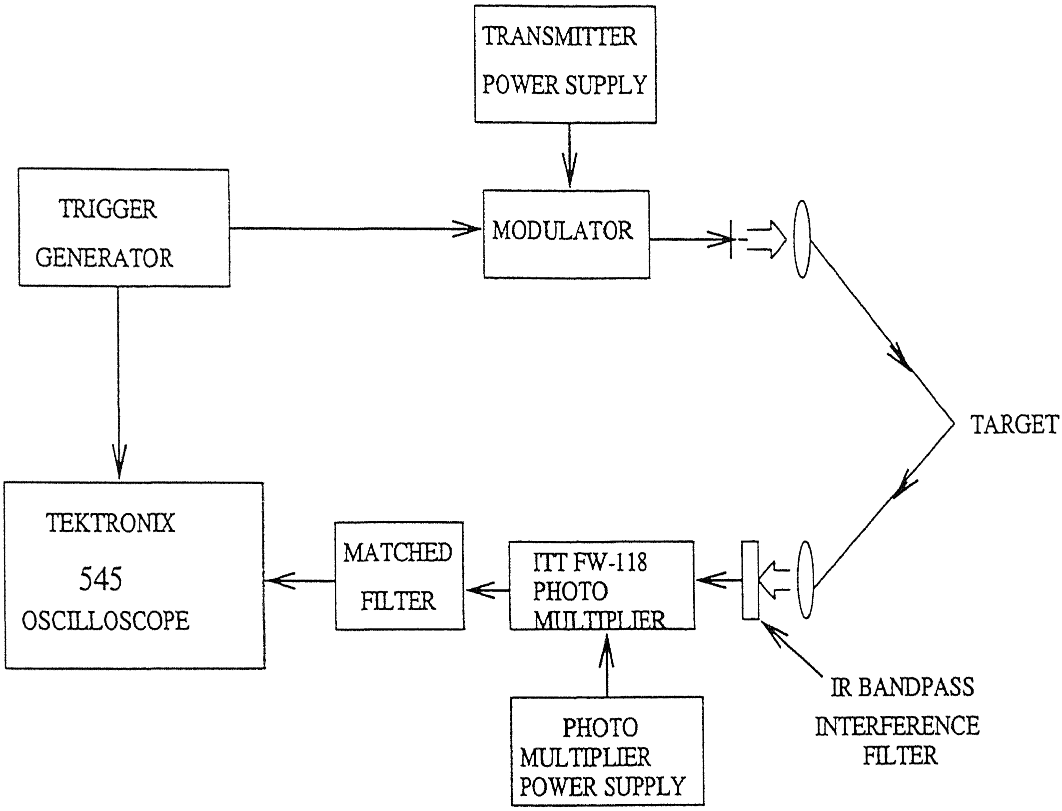

Figure 2.2: Block Diagram of the GaAs Laser Radar

In the above radar the modulator consists of a 5-section, 4 ohm lumped constant delay line network. The circuit diagram of the modulator is shown in Fig 2.3. The matched filter in the radar is a single pulse video delay line integrator. The detected video pulse is displayed on an A-scope for viewing and evaluation.

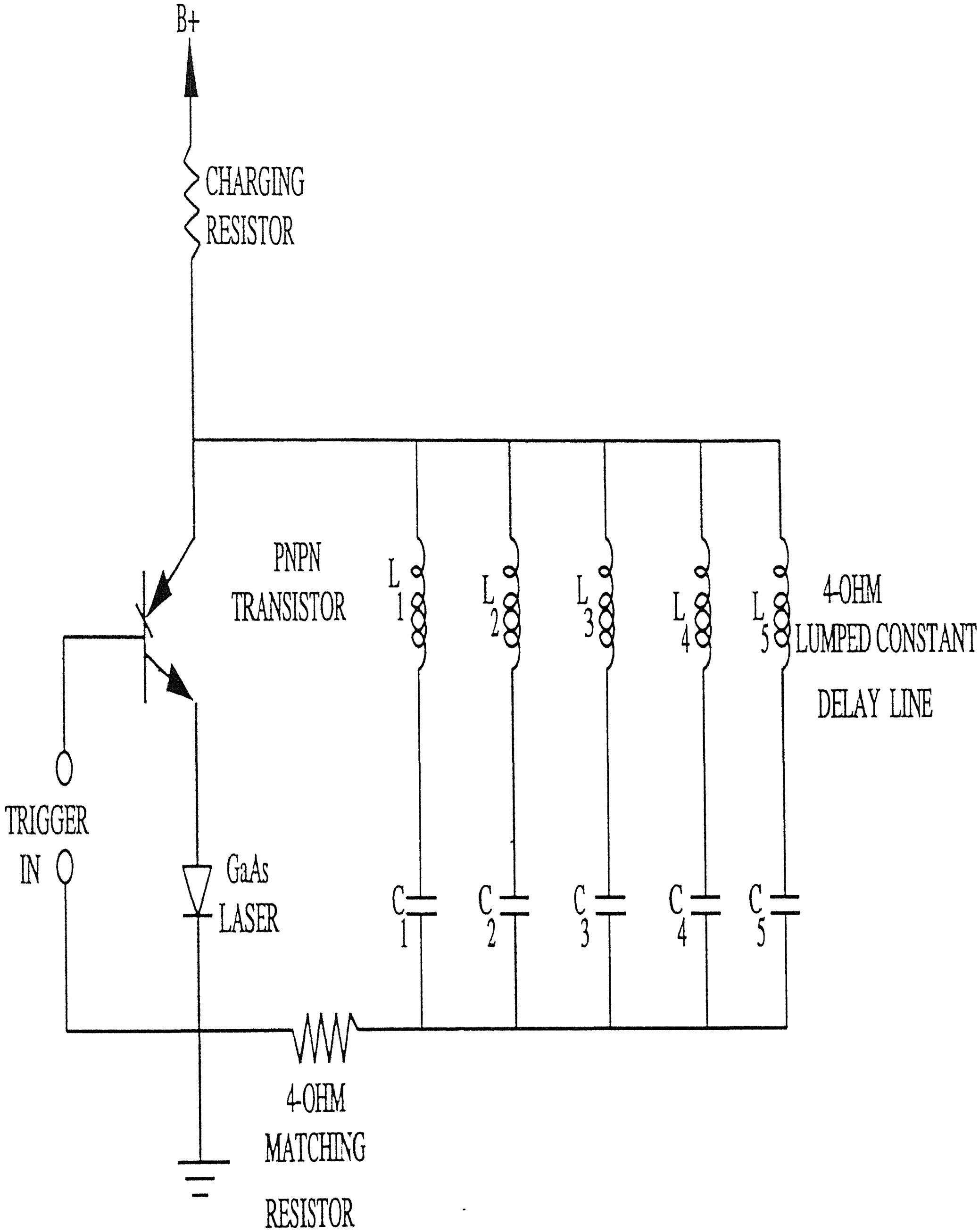

Figure 2.3: Circuit diagram of the GaAs Laser Radar Modulator

2.2 Phase Difference Measurement Methods

In this section three different methods for measuring small distances are explained.

2.2.1 Distance measurement by wavelength shift of laser diode light[8]

This is a method for measuring distances larger than the wavelength of light with a laser diode interferometer. This method uses the fact that the wavelength of the emitted light of a laser diode varies in proportion to its injection current.

Principle

Fig 2.4 shows a schematic diagram of this method.

The laser diode(LD) is operated at a single longitudinal mode. The light emitted by the laser diode is collimated by lens CL and is led to a Michelson interferometer. The difference "L" between the path lengths of the two arms is twice as long as the measuring distance "D". The corresponding phase difference is expressed as $2\pi L/\lambda$, where λ is the wavelength of laser light. When the light wavelength is changed from λ to $\lambda + \Delta\lambda$ by a change in the laser injection current, the phase difference also changes. The change is given by

$$\Delta\phi = 2\pi L(1/\lambda - 1/\lambda + \Delta\lambda) \tag{2.4}$$

Hence if λ and $\Delta\lambda$ are known "L" can be obtained by measuring difference between the phase differences. As the wavelength shift is much smaller than the wavelength itself the above eqation can be written as

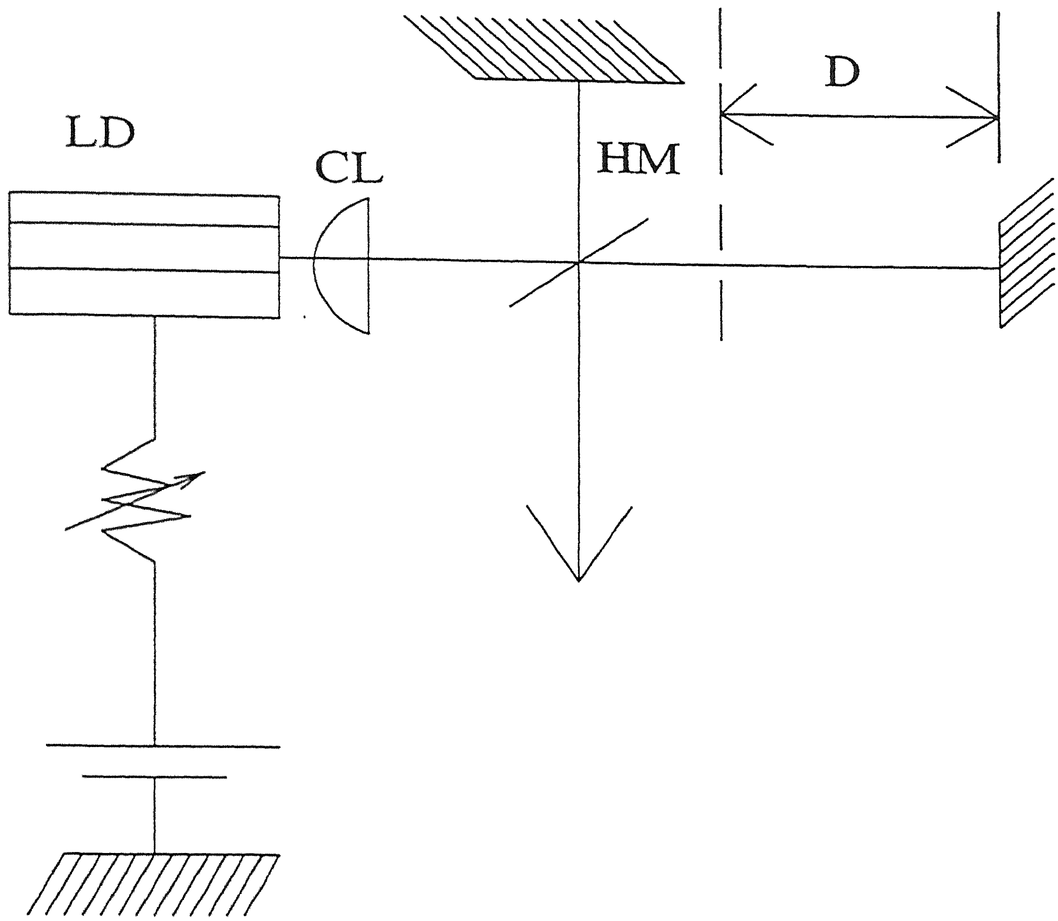

Figure 2.4: Diagram Showing The Measurement Principle

$$\Delta\phi = 2\pi L \Delta\lambda / \lambda^2 \tag{2.5}$$

Because $\Delta\lambda$ is proportional to the change in the injection current, this phase variation $\Delta\phi$ is also proportional to the variation in the injection current.

Light wavelength and intensity from a laser, vary with injection current and temperature. The wavelength increases when the injection current increases slightly. The wavelength also increases when the temperature increases. Generally, the rate of increases are $\approx 0.005nm/mA$ at 0.8 μm wavelength and $\approx 0.04nm/^oC$. These values are slightly different for different lasers.

In principle, the wavelength change $\delta\lambda$ caused by a slow variation in temper-

ature or drift of the injection current does not seriously affect the measured value. If an intentional change of wavelength $\Delta\lambda$ is independent of $\delta\lambda$ the phase change $\Delta\phi'$ is expressed as

$$\Delta\phi' = 2\pi L\Delta\lambda/(\lambda + \delta\lambda)^2 \tag{2.6}$$

The ratio of $\Delta\phi'$ to $\Delta\phi$ is given approximately as

$$\frac{\Delta\phi'}{\Delta\phi} = 1 + 2\delta\lambda/\lambda \tag{2.7}$$

The relative error is given by the ratio $2\delta\lambda/\lambda$

The independence of $\Delta\lambda$ on $\delta\lambda$ means the linear relationship between wavelength and injection current. This linearity holds as long as the mode jump is not caused by the wavelength change $\delta\lambda$.

When the injection current variation is large the longitudinal mode jumps to another mode. This mode jump restricts the range of the proportional wavelength change. The resolution of this method can be as good as 1μm at a measuring range of a few centimeters.

2.2.2 Interferometric Laser Range finder using a Frequency Modulated Diode Laser[9]

This is a method for interferometrically measuring distances to rough surfaces with submillimeter resolution. The measuring range can be made as large as hundreds of millimeters. This method uses sinusoidal wavelength modulation of the laser diode. It differs from the earlier method(distance measurement by the wavelength shift of the laser diode light) in the way the optical path difference(OPD) in the

interferometer is determined.

This method is not based on a phase measurement to determine the OPD. OPD can be measured by determinig the relative signal power present in one harmonic of the periodic time varying interference signal. For the purpose of normalisation, the measured signal power will be taken relative to the signal power present in another harmonic of the interference signal. The measured signal thus obtained will be only a function of the OPD and the amplitude of the periodic wavelength shift. Since no phase measurement is required the method can also be used in situations where the phase variation $2\pi L\Delta\lambda/\lambda^2$ exceeds 2π. Hence the measuring range can be made as large as tens of centimeters. Fig 2.5 shows the basic setup of the Interferometer.

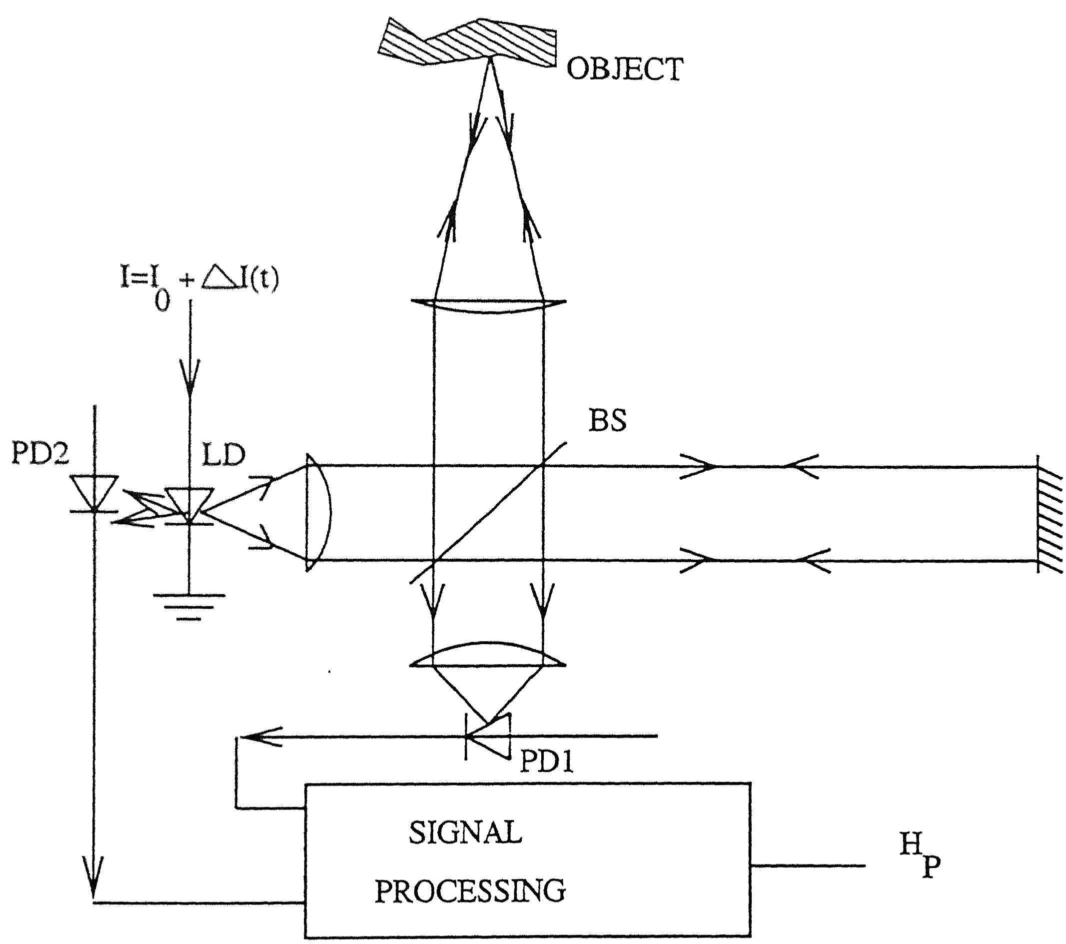

Figure 2.5: Basic configuration of the interferometric Range finder using a frequency modulated diode laser

The modulation of the laser injection current I results in both an intensity modulation [P(t)] and a frequency modulation[V(t)]:

$$P(t) = P_o[1 + m cos(2\pi f_o t)] \tag{2.8}$$

$$V(t) = V_o + \Delta V cos(2\pi f_o t + \phi) \tag{2.9}$$

P_o is the average intensity and V_o is the average optical frequency. m is the modulation depth of the periodic intensity variation and ΔV is the amplitude of the optical frequency deviation. The modulation frequency of the current modulation is f_o. A possible phase shift between the current modulation and the optical frequency deviation is accounted for by the term ϕ. This phase shift is irrelevant and can be omitted. The detuning of the optical frequency is caused by the laser current induced temperature variations of the laser cavity. These temperature variations cause changes in the effective cavity length, which in turn alter the optical frequency.

Apart from a constant factor, the optical power detected by the photo-diode PD1 can be described by

$$P_T(t, T) = P(t) + \gamma^2 P(t-\tau) + 2\gamma\sqrt{P(t)P(t-\tau)} cos[2\pi \int_{t-\tau}^{t} V(t')dt'] \tag{2.10}$$

The fraction of the optical power that is scattered from the rough surface into the interferometer is denoted by γ^2. τ is the time of flight difference between the two arms of the interferometer. On the assumption that $2\pi f_o \tau$ is much less than 1 and γ^2 is much less than 1, $P_T(t,\tau)$ can be approximated very accurately by

$$P_T(t, \tau) = P(t) + 2\gamma P(t) cos(2\pi[V_o \tau + \Delta V \tau cos(2\pi f_o t)]) \tag{2.11}$$

As interference signal (i.e the second term on the right-hand side of the above equation) is only of interest, by detecting the optical power at the rear laser mirror with detector PD2 and subtracting this signal in the proper amount from $P_T(t,\tau)$, P(t) can be eliminated. The subtraction should be done very accurately since the interference term is usually orders of magnitude smaller than P(t). For a proper determination of τ (or equivalently the OPD), amplitude modulation, P(t) in the

interference term is also to be eliminated. This can be achieved by dividing $P_T(t,\tau)$ by $1 + m\cos(2\pi f_s t)$. The time of flight difference τ can be determined by expanding $P_T(t,\tau)$ in a Fourier series, which yields the amplitude spectrum.

2.2.3 Range finding using a Frequency Modulated Laser Diode[10]

This is a coherent-optical time-of-flight range finding technique. Target range can be determined by modulating a laser diode's optical frequency and measuring the change in the phase of the light reflected back into the laser. Target velocity as well as range can be measured using this approach. A range resolution of 1cm requires 70ps resolution in the optical time-of- flight measurement. Using this method distance can be measured with sub centimeter resolution over a 1.5m range.

This method uses a frequency modulated optical source. The light reflected by the target is coherently detected to obtain the frequency dependence of the round trip optical phase shift. The distance "L" from the laser to the reflective target can be determined from the laser frequency deviation Δf, which produces one full cycle of phase change in the light fed back into the laser from the target. The two quantities are related by the equation $\Delta f = c/2L$, where c is the speed of light. The laser frequency is tuned by modulating the laser diode drive current. An increase in drive current shifts the laser emission to a slightly longer wavelength by increasing the laser cavity's temperature and refractive index. The dependence of the reflected light's phase on the source frequency is obtained by monitoring the laser diode output power while tuning the laser frequency. The external reflector effectively modulates the reflectance of the laser diodes front facet. Conditions of in-phase feedback are indicated by maximum deviation of the laser's output power from the laser's free running output power at the same current. Identification of the phase cycles of the reflected light is further simplified by the laser diode's tendency

to lock to one of the resonant frequencies of the external cavity introduced by the target. The reflective target and laser front facet form an external cavity of length L, where L is much larger than the optical length of laser diode cavity. When subject to feedback from the target, the laser diode will lock to the external cavity resonant frequency closest to the frequency at which the laser would operate without feed back.

When the laser's free running frequency is tuned by modulating the diode drive current, mode hops occur at intervals of free running frequency equal to the frequency difference between consecutive external cavity modes, $c/2L$. These mode hops introduce discontinuities in the laser output power and are readily detected by differentiating the signal from the laser power monitor. Range is determined by counting the number of mode hops N that result from a laser frequency variation of magnitude Δf. The distance to the target is given by $L = Nc/2\Delta f$. The resolution in range is that corresponding to a one count uncertainty or $\Delta L = c/2\Delta f$. Fig 2.6 shows the schematic diagram of an experimental circuit.

The light emitted from the front facet of a single mode laser diode is collimated by a graded-index rod micro-lens. Light emitted from the laser's rear facet is monitored by a photo-diode within the laser diode package. The photo-diode current is amplified by a transimpedance amplifier with 100-kHz bandwidth. The oscilloscope displays traces of the amplifier output both direct coupled and high pass filtered. The laser diode current is modulated with a symmetrical triangular wave. At each distance L the number of mode hops N during the upward current ramp will be obtained from the oscilloscope display. Fig 2.7 shows graph of number of mode hops vs target range L for a range finder calibrated by positioning a paper target at different distances. The calculated range finder calibration is L= N(0.37cm)

Target range can be obtained from the figure depending on the number of mode hops. Typical oscilloscope displays are also shown. An attempt has been

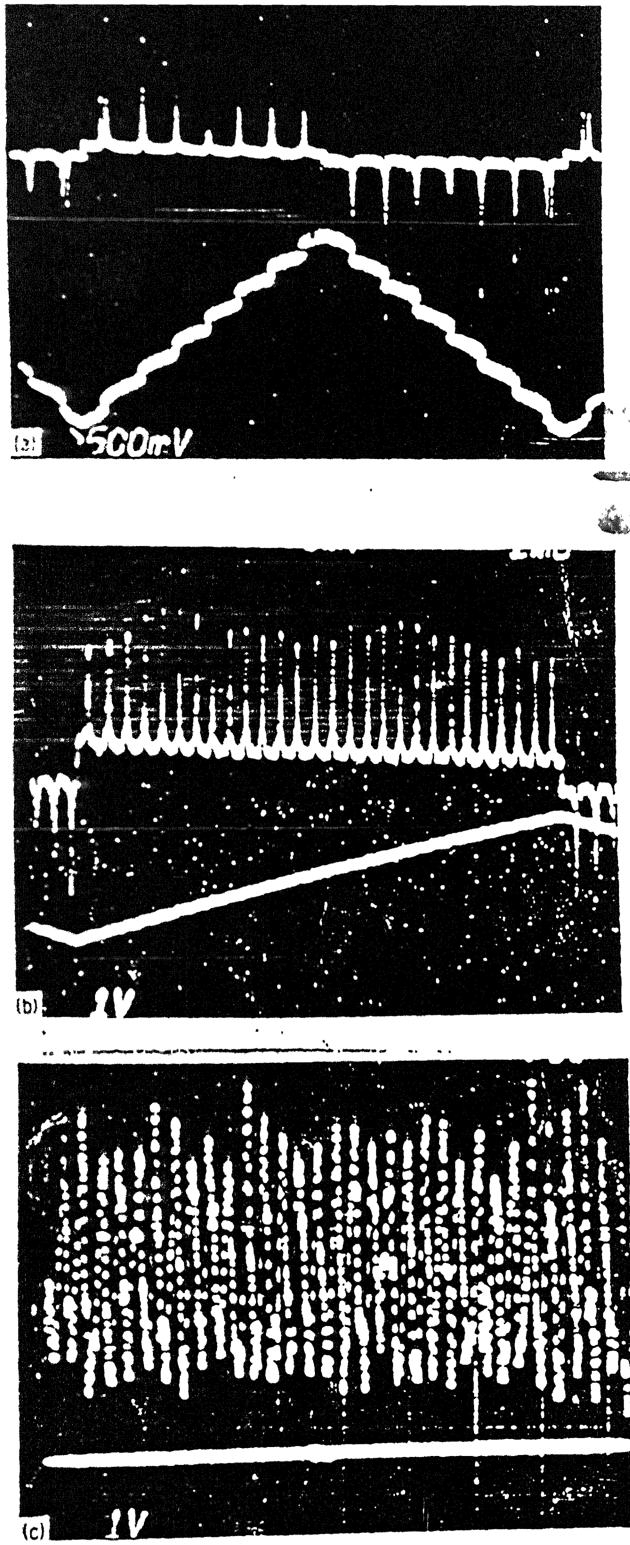

PLATE 1

Typical oscilloscope displays for stationary targets. The lower trace is direct-coupled, and the upper trace is high-pass filtered: (a) Scotchlite target at 2.4 cm; (b) and (c) paper target at 10cm and 100cm, respectively[10]

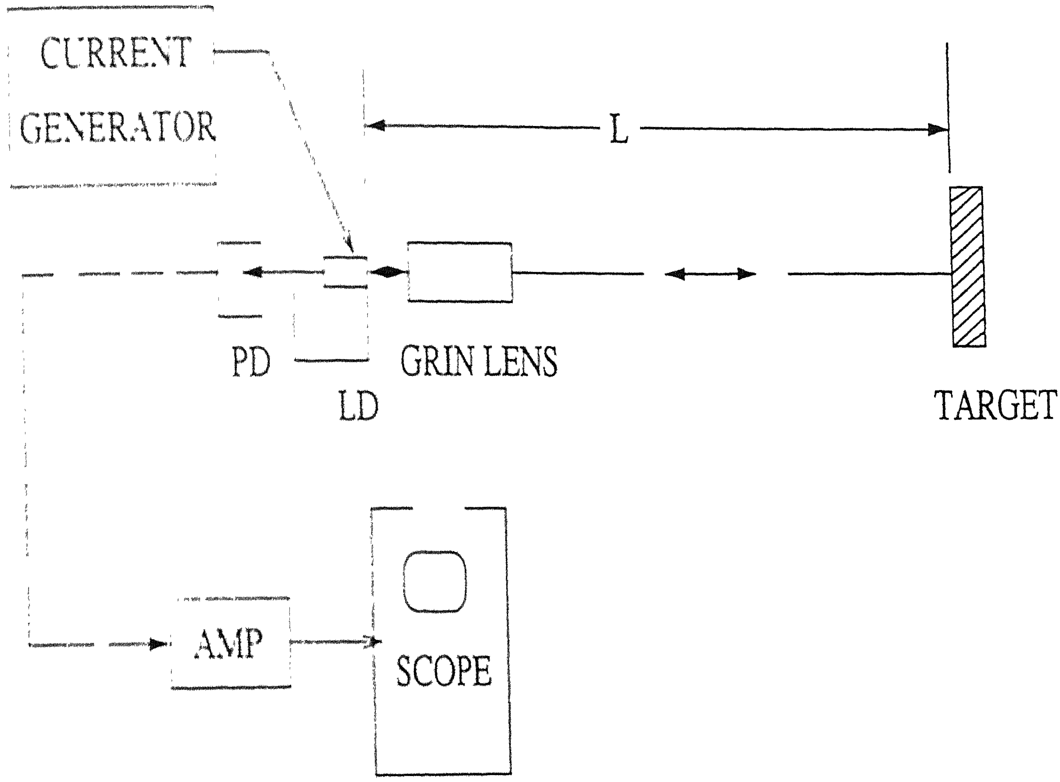

Figure 2.6: Schematic Diagram of an Experimental Circuit

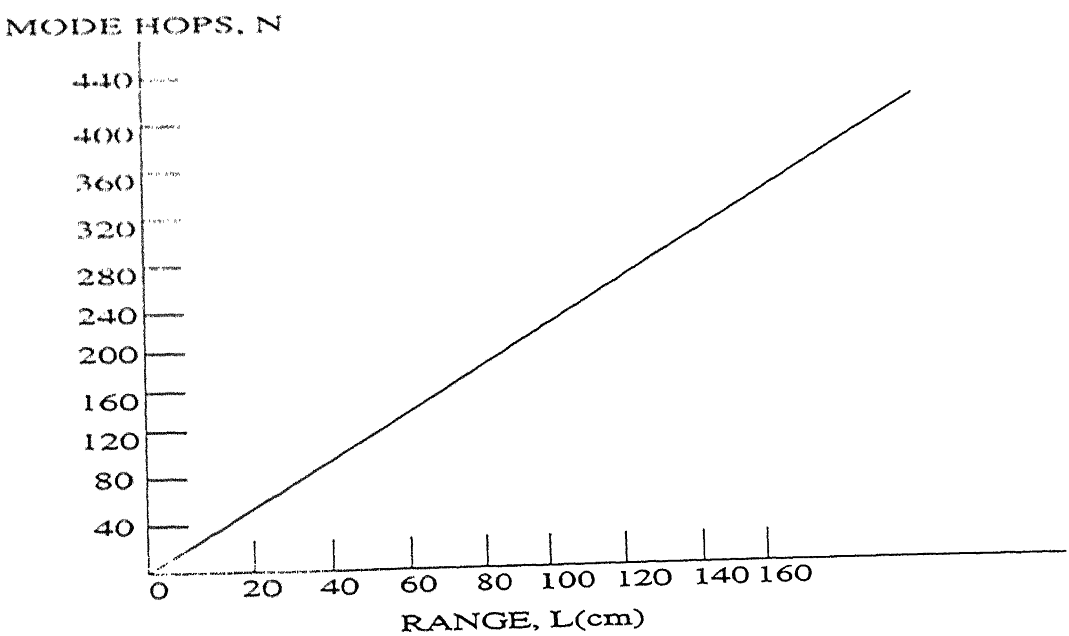

Figure 2.7: Number of mode hops N vs target range L [10]

made to implement this scheme as part of our study.

Chapter 3

Design and Implementation of a Range Finder using Frequency Modulated Laser Diode

In this chapter the circuit design and implementation of a range finder discussed in Sec.2.2.3 are given.

In our implementation of the above range finder, some modifications were necessary as compared to the one discussed in Sec.2.2.3. Our laser diode was a packaged one, with built in collimating optics and driver circuitry. Hence the laser diode drive current had to be changed by making small changes in the supply voltage. As a photodiode was not included in the laser diode package a beam splitter was used to get the reference and the reflected beams. Block diagram of our range finder is shown in Fig 3.1.

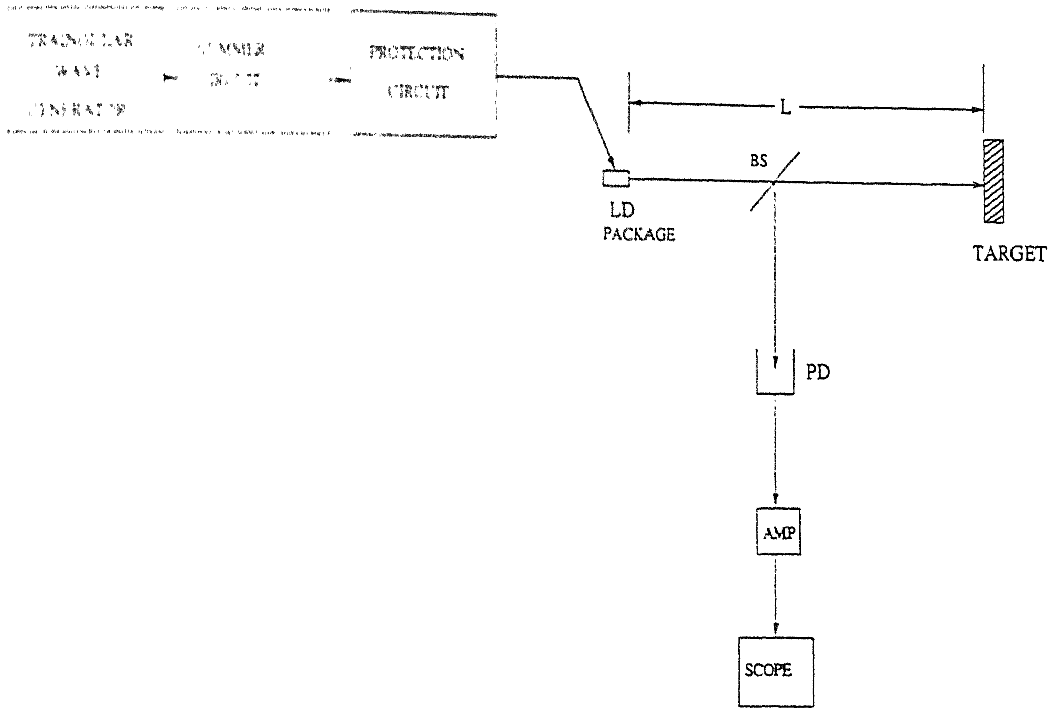

Figure 3.1: Schematic diagram of the range finder

3.1 Design Considerations of Subsystems

The major subsystems of the range finder are the laser driver circuit (consisting of the triangular wave generator, summer and laser protection circuits) and the photo-diode amplifier circuit.

3.1.1 Laser Driver Circuit

Triangular Wave Generator:

The laser diode is driven by a triangular wave of amplitude 0.6V (peak-to-peak) and time period of 29.3ms, superimposed on a dc voltage of 2.5V and connected through a protection circuit. The circuit of the triangular wave generator is shown in Fig 3.2

The generator consists of a comparator A_1 and an integrator A_2. The comparator A_1 compares the voltage at point "P" continuously with the inverting

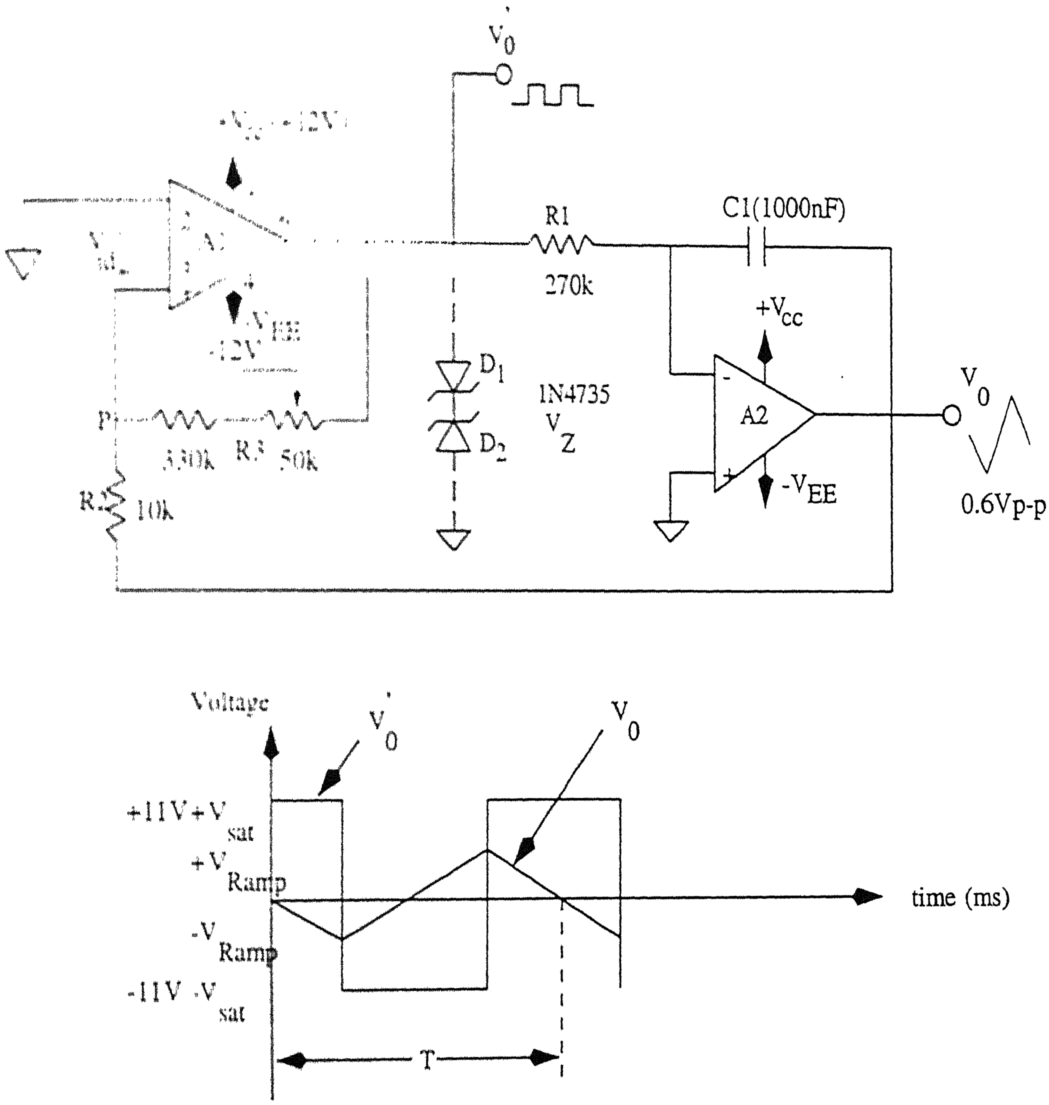

Figure 3.2: Triangular Wave Generator[5]

input that is 0 volts. When the voltage at "P" goes slightly below or above "0V", the output of A_1 is at the negative or positive saturation level, respectively. The operation of the circuit can be explained as follows.

If the output of A_1 is at positive saturation $+V_{sat}(\approx V_{CC})$, this $+V_{sat}$ is the input to the integrator A_2. The output of A_2, will be a negative going ramp. Thus one end of the voltage divider R_2 - R_3 is the positive saturation voltage $+V_{sat}$ of A_1 and the other is the negative going ramp of A_2. When the negative going ramp attains a certain value -V_{ramp}, point "P" is slightly below "0V". Hence the output of A_1 will switch from positive saturation to negative saturation -$V_{sat}(\approx$-$V_{EE})$. This

means that the output of A_2 will now stop going negatively and will begin to go positively. The output of A_2 will continue to raise until it reaches $+V_{ramp}$. Now the point "P" is slightly above "0V". Hence the output of A_1 switches back to the positive saturation level V_{sat}. The sequence then repeats. The output waveform is also shown in the figure.

The frequencies of the square wave and the triangular wave are the same. The amplitude of the square wave is a function of dc supply voltages. A desired amplitude can be obtained by using appropriate zeners at the output of A_1.The amplitude and the frequency of the triangular wave can be determined as given below.

When the output of comparator A_1 is $+V_{sat}$, the output of the integrator A_2 steadily decreases until it reaches -V_{ramp}. At this time the output of A_1 switches from $+V_{sat}$ to -V_{sat}. Just before this switching occurs the voltage at point "P" is 0V. This means that -V_{ramp} must be developed across R_2 and $+V_{sat}$ must be developed across R_3. That is

$$\frac{-V_{ramp}}{R_2} = -\frac{+V_{sat}}{R_3} \tag{3.1}$$

or $-V_{ramp} = -\frac{R_2}{R_3}(+V_{sat})$

Similarly, $+V_{ramp}$, the output voltage of A_2 at which the output of A_1 switches from -V_{sat} to $+V_{sat}$ is given by

$$+V_{ramp} = -\frac{R_2}{R_3}(-V_{sat}) \tag{3.2}$$

The peak to peak output amplitude of the triangular wave is

$$V_{Op-p} = +V_{ramp} - (-V_{ramp})$$

$$V_{Op-p} = 2\frac{R_2}{R_3}(V_{sat})$$

where $V_{sat} = |+V_{sat}| = |-V_{sat}|$

The time it takes for the output waveform to swing from -V_{ramp} to $+V_{ramp}$ or from $+V_{ramp}$ to -V_{ramp} is equal to half the time period $T/2$. This time can be calculated from the integrator output equation

$$V_O = -\frac{1}{R_1C_1}\int_0^{T/2} V_i dt + C \tag{3.3}$$

Here V_i = -V_{sat}, $V_O = V_{Op-p}$ and taking C = 0

$$V_{Op-p} = -\frac{1}{R_1C_1}\int_0^{T/2}(-V_{sat})dt = \frac{V_{sat}}{R_1C_1}(T/2)$$

$$T/2 = \frac{V_O(PP)}{V_{sat}}(R_1C_1)$$

$$T = 2R_1C_1\frac{V_O(PP)}{V_{sat}} \tag{3.4}$$

where $V_{sat} = |+V_{sat}| = |-V_{sat}|$ As $V_{Op-p} = 2\frac{R_2}{R_3}(V_{sat})$

$$T = \frac{4R_1C_1R_2}{R_3} \tag{3.5}$$

The frequency of oscillation is $f_O = 1/T$. For the waveform used in the experiment V_{Op-p} = 0.6V and T=29.3ms

Summer and Laser Protection Circuits:

Output of the above circuit has to be suitably modified to match the driving requirements of the laser transmitter. The laser transmitter has a nominal supply voltage of 3V for an output of 5mW. As it was not possible to directly drive the laser diode (LD) due to the packaged nature of the laser source, drive current was changed indirectly by varying the supply voltage from about 2.2 V to 2.8V. For this purpose the triangular waveform is superimposed on a dc voltage of 2.5V using a summer circuit. It was neccessary to use an over-voltage protection circuit as the voltage across the laser diode had to be kept within 3V. Fig 3.3 shows the summer circuit and the laser diode protection circuit used in our implementation.

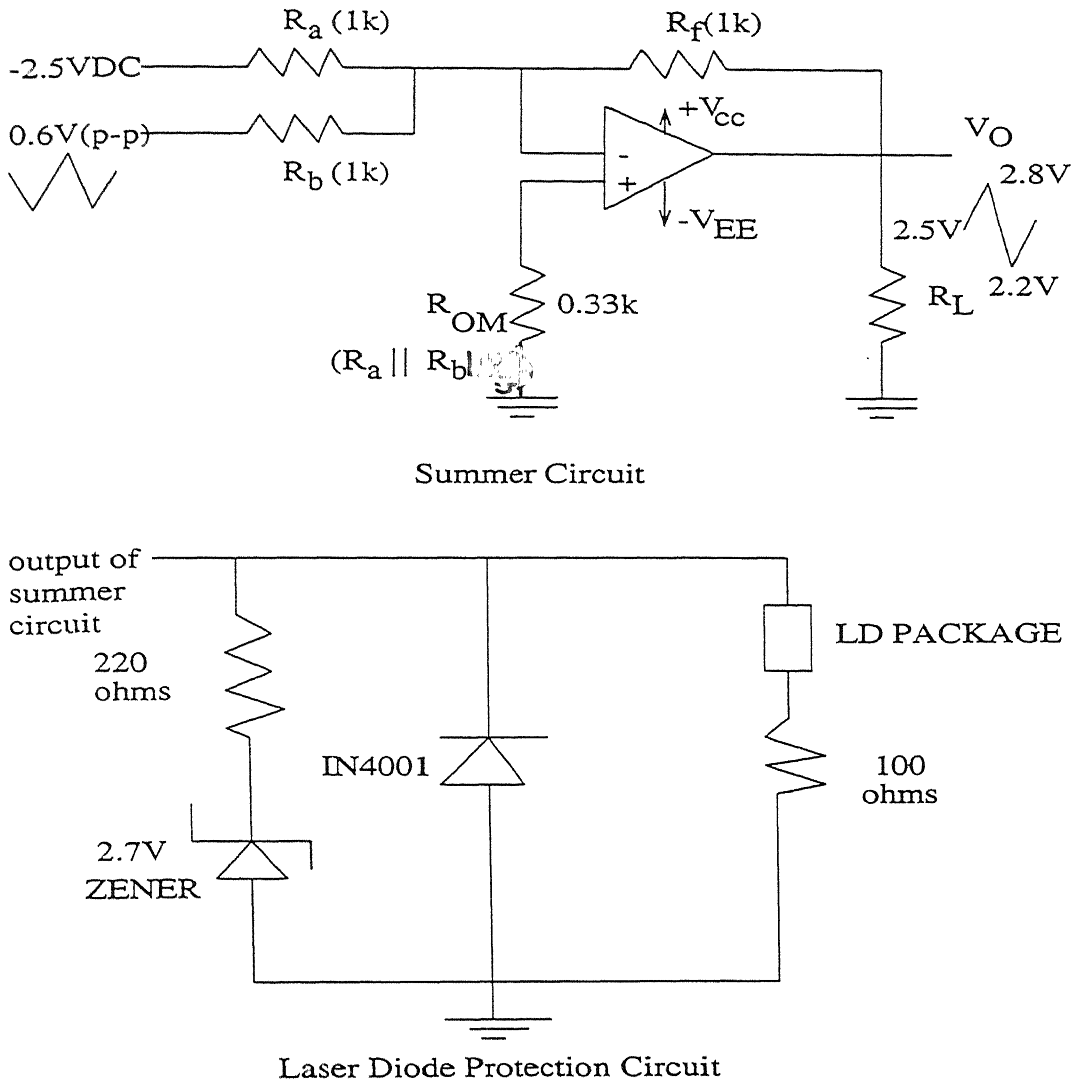

Figure 3.3: Summer Circuit and Laser Diode Protection Circuit

3.1.2 Photodiode Amplifier Circuit

The intensity of light falling on the photodiode due to the reflected beam is very low compared to the reference beam from the beam splitter. In order to amplify the output of the photodiode an opamp based transimpedance amplifier circuit has been used. This circuit is shown in Fig 3.4.

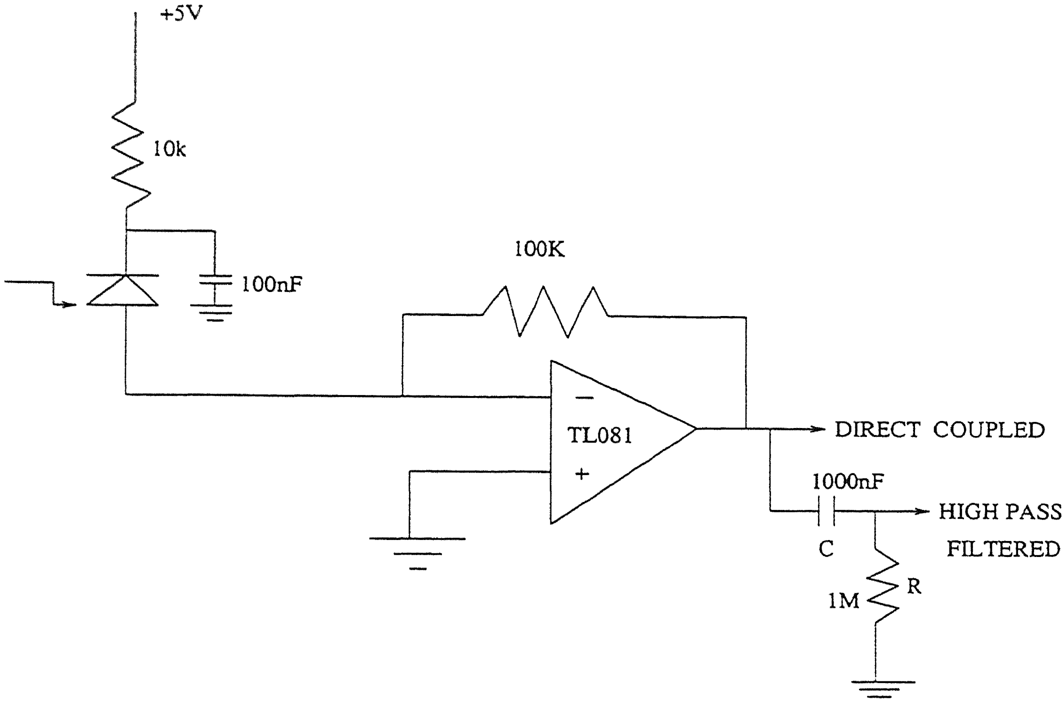

Figure 3.4: Photodiode Amplifier Circuit

3.2 Experimental Procedure

Block schematic diagram of the implemented range finder was shown in Fig3.1. Light emitted from the laser (645nm) is passed through a beam splitter and then to the target (targets used were white papers or metal plates). A part of the light reflected from the target is detected by the silicon PIN photodiode. The photodiode output is amplified by a high bandwidth amplifier. The amplifier outputs, viz. direct coupled and high-pass filtered, are given to an oscilloscope. From the oscilloscope display the number of mode hops are counted and from them distance to the target from the laser is calculated.

3.2.1 System Performance

The circuit of a symmetrical triangular wave of peak to peak amplitude of 0.6V and time period of 29.3ms was designed and constructed using TL081/μA741 opamps. It was observed that a symmetrical triangular wave of the required amplitude and time period were produced by the desined waveform generator. The summer circuit superimposed the above output on a 2.5V dc. Measured output of the summer cum laser diode protection circuit was observed to be varying from 2.2V to 2.8V. The LD output power varied from a lower value to a higher one in accordance with the above input variations. A high bandwidth amplifier circuit to amplify the output of the photo diode was also constructed. An attempt has been made to measure the distances of different targets by mounting the setup as shown in Fig 3.1 on an optical table using XYZ and XY mounts. The required oscilloscope traces were not obtained for reasons not known. As the laser diode suddenly failed due to unknown reasons, the experiment could not be completed. Hence it was not possible to do evaluate the overall performance of our implementation.

Chapter 4

Conclusions

In this thesis an effort has been made to study various laser distance measurement techniques.

A broad classification of optical distance measurement, the basic principles of laser distance measurement, their applications and advantages and disadvantages have been reviewed. The requirements of a laser radar was discussed. Example of a semiconductor laser radar was given. Different examples of phase difference methods were also given.

Implemetation of a range-finder using a frequency modulated laser diode was taken up. The laser drive circuit consisted of a triangle wave generator, summer and laser protection circuits. A high bandwidth photodiode amplifier was also made. But due to failure of the laser package it was not possible to take measurements using our implementation.

From our study it can be concluded that because of their spatial and temporal coherence lasers can be used in high resolution distance measurements.

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